

The positive impacts of farm land fragmentation in Rwanda

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ARTICLE INFO

Keywords:

Land fragmentation
Impact assessment
Climate resilience
Food security

ABSTRACT

Land fragmentation and land consolidation are two interrelated concepts of land management. The dominant discourse is that fragmented land ownership and land use tend to be ineffective and unwanted, and land consolidation is then a solution to this quandary. Not surprisingly, in countries such as Rwanda, the majority of the governmental strategies highlight the negative effects of fragmentation. However, the effects of land fragmentation have been dual. Its positive side has often been overlooked by policy makers and the research community. Therefore, this study investigates to which degree one can benefit from farmland fragmentation, especially in the context of food security at the household level and of climate change vulnerability. The goal of this article is to expand the current land fragmentation discourse and describe in which context specific types of land fragmentation may be just as sustainable as opting for land consolidation. The guiding hypothesis hereby is that there is a high level of fragmented land ownership yet, that physical (location, use, internal, shape and value) fragmentation acts as a risk management strategy which positively impacts the nutritional balance for food quality and food sustainability as components of food security.

Conceptually, land fragmentation can be seen from multiple lenses. It can be seen as a land use concept (emphasizing variation in manner of agricultural production, variety of crops, frequency of harvesting, etc.). It can also be seen as a geodetic concept (emphasizing variation in shape and size of parcels on the one hand, and variation in land ownership on the other hand). Additionally, it can be seen as a spatial planning and intervention concept (emphasizing the urgency and need for order, structure and alignment of space). In our article we look at fragmentation (and the variation thereof) in all three ways. If within an area, the utilization, ownership, leasehold, shape, size and location of parcels and spatial policies vary more than average (as compared to a similar area), then we consider it a fragmented landscape. Once we find a case of such a landscape, then we are able to investigate why and/or under which conditions (and by which drivers) this 'fragmented' landscape has emerged and what are the implications. This is the main question under investigation in this research.

The research relies on a mixed methods research approach via household surveys with 98 random respondents in Gashora sector, Bugesera District, Eastern province of Rwanda. The data collection included further 7 key informants' interviews, a focus group discussion, field observations of current plot sizes and land uses, and the review of the existing literature on the topic.

The findings indicate that a high level of fragmentation exists, both in terms of land ownership (visible and hidden) and physical landscape. The dominant reasons are that land users perceive this as an effective risks management strategy which would positively affect food quality, food sustainability and food security. Multiple land holdings with different shapes in different locations allow farmers to grow multiple crops with different adaptation capacities in different growing conditions (soil type, slope, microclimate variations, etc.). Furthermore, fragmentation seems to help reduce land ownership and use related conflicts despite its negative impacts on agriculture production efficiency, especially the loss of land through boundaries and the increase in boundaries related conflicts.

Unlike previous studies on land fragmentation, we posit that environmental and agricultural policies should take both negative and positive impacts of land fragmentation into account equally as sustainable and resilient solutions, given the right circumstances and contexts, especially for vulnerable and food insecure areas in Rwanda.

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<https://doi.org/10.1016/j.landusepol.2018.11.005>

Received 14 June 2018; Received in revised form 3 November 2018; Accepted 3 November 2018

Available online 24 November 2018

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1. Introduction

Both the unique topography and high population densities have contributed to a fragmented landscape in Rwanda. With a current population density of 462 people per km² (NISR, 2015) combined with decreasing land availability due to fast urbanization, complex settlement and farming opportunities due to a mountainous and hilly geomorphology, and an increasing risk of erosion due to climate change, fragmented landscapes and fragmented land tenure has gradually increased in Rwanda. Due to the increasing competition and pressure of the growing population to meet their basic needs for food, energy and shelter on limited land resources in Rwanda, land has become a contested asset, scarce in nature and containing many competitive interests. That is why land management is a must. Generally, land fragmentation has negatively affected agricultural production and food quantity. However, in Rwanda, whether land fragmentation is only causing negative effects is strongly debated (Kahiresan and MINAGRI (2012), Konguka (2013); GoR (2014); Musahara et al. (2014). Most governmental reports and current strategies such as the Land Use Consolidation (LUC) Program, Article 30 of the Law Governing Lands in Rwanda view land fragmentation as negative, and do not see any positive sides to it. On the other hand, there is no comprehensive knowledge concerning the circumstances under which land fragmentation derives significant negative or positive effects. Neither is there sufficient knowledge on the causes and implications of different kinds of land fragmentation.

Since the majority of the population (more than 72%) lives off subsistence agriculture (NISR, 2015), the effects of land fragmentation are always linked to the volume of agriculture production, thereby dividing the Rwandan research community. Research by GoR (2004), Musahara and Huggins (2005), Kahiresan and MINAGRI (2012), Ntirenganya (2012 cited in USAID, 2014), Mbonigaba and Dusengimana (2013) consider that land fragmentation has a negative impact on food security. The question is to which extent land fragmentation, either in the form of a deliberate or a gradual land intervention can be considered as a “responsible land management” practice (de Vries and Chigbu, 2017: 68). The argument is that land fragmentation can be expressed as both a fragmentation of use and ownership. The agriculture production tends to be small at all scales due to this fragmentation through the reduction of its efficiency at the national level, since the yield per HA is small when agriculture is done on small plots far away from the residence, as a result of which production costs are high. They also advance the idea that land fragmentation reduces the size of land under cultivation through the loss or wastage of some areas and farm sizes under boundaries.

Chigbu and Kalashyan (2015: 10) warn that land consolidation should not be about “a mere reallocation of parcels to remove effects of fragmentation” as fragmentation is not always a problematic issue. This explains why Konguka (2013) finds land fragmentation to have positive impacts on food security, since it acts as a protection strategy against environmental risks such as change in weather patterns, by diversifying different crops in different locations. Konguka (2013) advances the idea that holding different plots in different areas with different soils, slopes, micro-climatic variations sustain the agriculture production at the household level within the subsistence agriculture all over the year, thereby supporting the nutritional balance as a component of food security. This goes in line with the Sustainable Development Goals (SDGs 2, 13 and 15) which stipulate the focus on the climate smart agriculture, requiring the use of multiple crops with different adaptation capabilities on small plots spread in different areas, rather than the widely known market-oriented agriculture on big farms often promoting the monoculture.

Coping with this very complex issue needs a sound knowledge about the level, forms and causes of land fragmentation along with all its effects, and the components of food security at both national and household levels and their relationships. Unfortunately, prior to the

lack of key knowledge and the literature gap about the above problem, the majority of the governmental programs to tackle it, including the Farm Land Use Consolidation (LUC) program and the prohibition of the subdivision of agricultural land which could result in parcels less than 1HA (GoR, 2013), have been recently found to be inefficient, ineffective and non-participatory, *since they are only oriented towards coping with farm land use and ownership fragmentation and act as a bridge of climate change towards food insecurity through the quite imposed monoculture*. Hence, there is a need to prepare sustainable and climate resilient solutions to the above problem by considering the harmonization of environmental and agriculture policies which require the consideration of both negative and positive impacts of land fragmentation.

Therefore, this study investigates to which extent assumed or perceived positive impacts of land fragmentation play a role in the decisions of individual farmers and the decisions of governmental agencies as a whole. The issue of fragmentation is connected to the attributes of food security related decisions and effects at household level in Rwanda. Once the correlations of fragmentation features and food security features are evident, it is possible to propose the alternative sustainable solutions to address land fragmentation problem and adapt the current negative discourse. Unlike previous researches on the topic in Rwanda, this article assesses the level, different forms, and causes of land fragmentation and shows their effects focusing on the positive ones on different dimensions of food security in terms of food quantity, food quality, food sustainability and food availability, using the case study of Gashora sector in Bugesera district. The research assumes that there is a high level of land ownership, use, shape, value, internal and location fragmentation, which act as risks management strategy thereby positively impacting on the nutritional balance for food quality and food sustainability as components of food security. The findings of this study will assist the government of Rwanda to develop appropriate country context specific and climate resilient policies and coping strategies to the problems of land fragmentation and food insecurity, and achieve its national sustainable development goals. This article focuses only on farm land fragmentation and food security at the household level.

This article is structured as follows: First, we conceptualise land fragmentation and food insecurity. Next, we describe the positive and negative implications of land fragmentation. Then, we present the applied data collection and data analysis methodology to achieve the study objectives. Finally, we present and interpret our empirical findings, respond to the main research question about the conditions, causes and effects of land fragmentation, and present recommendations for practitioners and for further research.

2. Theoretical perspective

2.1. The concept of land fragmentation: forms, characteristics, causes and measurements

There is no single commonly agreed definition of land fragmentation. Bentley (1987) defines it as the scattering of farmland, McPherson (1982) as a situation where there are many numbers of plots spatially separated, with the same owner. King and Burton (1982) characterize land fragmentation as a basic rural spatial problem whereby farms are poorly organized at different locations across an area. These conceptualizations focus however only on dispersed land owners and dispersed plot locations held by single owners without considering the variety in size, use and shape of the respective plots. Sundqvist and Lisa (2006) give a more concrete definition adapted from FAO (2003), which considers land fragmentation as a situation where a farming household possesses several non-contiguous land plots, often scattered over a wide area. They view it as a spatial concern with the spatial characteristics like the farm size, the number of land parcels belonging to the farm, the size and shape of land parcels, the size distribution of plots and the spatial distribution of plots. For de Vries (2016), the most common interpretation of land fragmentation relates to physical aspects

of fragmentation, i.e. holdings with a large number of small parcels scattered over a considerable area. In this regard, Sabates-Wheeler (2002) has shown land fragmentation as a multidimensional phenomenon with four dimensions such as: (1) physical fragmentation, (2) social fragmentation, (3) activity fragmentation and (4) ownership fragmentation. The same author argues that the physical fragmentation may imply any one or a combination of the following: (i) non-contiguous land parcels that are owned and tilled as a single enterprise; (ii) parcels that are distant from the owner's homes or from each other; or (iii) ownership of very small parcels.

There are different methods of measuring land fragmentation. They include the *Global Land Fragmentation Index* (Demetriou et al., 2013), the Januszewski index (janusi), the Simpson index (*SimpSi*) and the *Simmons fragmentation index* (Simons, 1988), among others. Each of these methods have different meanings and the absence of a real standard objective measure make it hard to decide if a farm is too fragmented or not fragmented at all. When comparing all those globally recognized measurement methods, land fragmentation is generally focusing on measurements of the physical shape and distribution of parcels, i.e. by determining the number of owners per a given land unit, area, region or land block (ownership fragmentation), the size of household landholding, the number of plots per household or farm, respective sizes of plots, their shapes, uses and their spatial distribution or locations from the household homestead along with their values in some cases. We can refer to this as physical fragmentation.

Generally, the forms of land fragmentation should be linked with each of the characteristics of land, such as its ownership, size, use, shape, value and location since their causes and effects also vary from type to type. However, most of the literature ignores the land location, value and shape fragmentation when analysing the impacts and causes of land fragmentation in general, which in turn leads to the development of broad and non-appropriate coping policies and strategies. King and Burton (1982); Bentley (1987), Van Dijk (2003a,b) cited in Hartvigsen (2014,2015a,b), Sundqvist and Lisa (2006); Sklenicka et al. (2014), and Hiironen et al. (2016) have limited the existing types of land fragmentation to the fragmentation of land ownership; land use; within a farm (or internal fragmentation); and separation of/discrepancy between ownership and use fragmentation. According to Van Dijk (2003a,b) cited in Hartvigsen (2014,2015a,b), land ownership fragmentation refers to the situation where the ownership of agricultural land is split between many owners of small and often badly shaped parcels (when there are many land owners on a small land block). For them, land use fragmentation refers to the number of users of lands which are not their own lands. This is generally considered as the number of tenants in the European land fragmentation and consolidation literature. Land is considered to be fragmented in use when there are many users on it. However, in the general context, land use fragmentation has to do with the actual use of land (whenever there are more than one land uses on a single farm or plot). This does not have anything to do with the number of users, since one user or owner can have multiple uses on a farmland. For this reason, the number of users can refer to a different type of fragmentation which is *Usership fragmentation* merely associated with *Ownership fragmentation* depending upon whether the users are using their own lands or not. In this article, the term land use fragmentation in the sense of land utilization fragmentation will be followed. Internal fragmentation is understood as the fragmentation within a farm (whenever a farm or household land holding is split into many small non-contiguous plots often scattered in different locations at long distances from the homestead and between the parcels). Separation of ownership and use involves the situation where there is a discrepancy between ownership and use, often shown by small number of land owners who use their lands. For Van Dijk (2003a,b), the reduction of land fragmentation occurs when the number of owners and/or users declines, the number of parcels per farm falls, and the share of owners that use land themselves raises.

Hartvigsen (2014,2015a,b) argues that land fragmentation and land

consolidation policies in Eastern and Central European countries were more concerned with land ownership and land use fragmentation. Drawing on Demetriou et al. (2013), he introduces a new form of fragmentation known as a *Hidden fragmentation* in ownership and use, when there is a co-ownership of a family land by many family or household members. Each household member tends to ask for his own part for individual use based on his use and food preferences. This has been found in countries like Bulgaria and Albania, and is likely to exist in Rwanda as well, as there is a restriction of the subdivision of family land with sizes less than 1 ha, and the encouragement of its co-ownership. He also referring to the studies of McPherson (1982) introduced the notion of *Excessive fragmentation*, which he defined to exist if the number of parcels in a farm exceeds its size. As an example, a 20 ha farm would be excessively fragmented if it consisted of more than 20 parcels (McPherson, 1982). He further refers to Bentley (1987) when mentioning that *Extensive fragmentation* exists when the parcels become so small that they are not economically viable which could often result in land abandonment. Recent studies conducted by Muchová (2017) in Slovakia, and Janus et al. (2018) in Poland introduced new more flexible approaches of calculating land fragmentation, but all of them were more oriented towards defending the benefits and the need for land consolidation projects both in case of physical and ownership fragmentation. Janus et al. (2018) have emphasized on the importance of aggregation of parcels or plots belonging to the same owner as it happens in land consolidation. They developed different parcel aggregation indexes which do only consider the number of plots belonging to the same owner before and after aggregation (after elimination of the boundaries) when calculating physical land fragmentation indicators through the so called phenomenon of neighbourhood of plots. This method does not show land fragmentation indicators to be considered and their calculations, neither gives any attention to land ownership fragmentation. On the other hand, Muchová (2017) gives more details on the calculation of land ownership fragmentation by considering multiple criteria like the number of owners per land unit area, the number of plots per unit land, the number of co-owners per parcel, the size of land, the size of plots, the average number of plots, average size of plots, average number of co-owners and different ratios, although his approach does also not consider some physical fragmentation features (uses and shapes of parcels). It however brings in a new idea of considering both external ownership fragmentation and internal ownership fragmentation (co-ownership) when preparing or evaluating land consolidation projects. Therefore, in this article, we use the above mentioned characteristics of land (ownership, size, use, shape, value and location), and split land fragmentation into two main forms such as: **Land ownership fragmentation** and **Physical land fragmentation** (land use, land value, land location, land shape and internal fragmentations). Land usership fragmentation will be often combined with land ownership fragmentation. Although there are no standard measurable indicators combining all the above forms besides the subjective and somehow incomplete indexes, the number of owners in a given land block, the number of household members (ownership fragmentation), the size of household land holding, the number of plots per household, the sizes of respective small plots and their averages, the shapes of those plots, their uses and their local distributions (physical fragmentation) have been considered.

According to King and Burton (1982); Hartvigsen (2014), there are four causes of fragmentation: (1) socio-cultural (inheritance laws, marriage, dowry culture); (2) economic (land market, land transactions); (3) physical (soil qualities, topography, location, shapes, etc); and (4) operational (land reforms, land policies, infrastructures development). Bizimana et al. (2004) advance the causes of land fragmentation to be mainly linked with the inheritance culture and laws, land reforms including land redistribution, restitution and land sharing programs in different countries after the conflicts, and the increasing population growth on limited, stable and scarce land resources. The urbanization and increasing land markets also have been found to put a

lot of pressure on land parcels, thereby increasing their continuous subdivision. The variations in land qualities (soil types, slopes, micro-climates, topography, etc) associated with the Egalitarian principles during inheritance and land reform processes have also been over time pointed out by different researchers like Keeler and Skuras (1990); Tan et al. (2006), Sklenicka and Salek (2008), Hristov (2009); Platonova et al. (2009); Sikor et al. (2009); Sklenicka et al. (2014); Ciaian et al. (2015) and Sky (2015), as one of the main causes of both physical and ownership fragmentation. According to these authors, the Egalitarian principle applied in many countries like Greece, China, Albania and Rwanda throughout the inheritance and land reform processes stipulates the distribution of land among all the heirs in qualitative and quantitative equal shares. All the members receive the pieces of land of the same sizes, same qualities from all locations and all classes and grades. They believe that lands are different and diverse in physical properties (flat, mountainous, various soil fertility status, etc), locations (far from the homestead, close to the house, close or far from irrigation facilities and roads, etc), types (arable land, grassland, etc), with different production potentials and suitability classes or grades. Therefore, family members prefer to have lands of all grades or classes through inheritance, land reforms, and land market, which leads to the subdivision of lands into small pieces scattered in different locations with various uses, thereby increasing the land ownership and physical fragmentation explained above. The marriage and dowry culture in some countries also exacerbates/worsens this problem, when the female household members get married and dislocate to the places located far away from their parcel shares in family lands. The subsistence motive reasons have been also advanced by some authors like Ciaian et al. (2015) as factors of diversification when family members with different reasons prefer to have different heterogeneous lands with different crops suitability for their crops diversification to meet their various dietary preferences. For the land market, most of the people prefer to buy additional lands of different qualities often located far away from their own farmed lands and homestead as it has been found difficult to get additional parcels contiguous and close to their already farmed own lands, thereby leading to the physical fragmentation (location and use). From the above literature considerations, it can be concluded that the forms of land fragmentation cause others (Ownership and/or usership fragmentation induce physical fragmentation and vice versa). Table A1/Appendix A in appendices section summarizes the attributes of land fragmentation in the literature and its implications.

In summary, from the above mentioned Table A1, we consider an area fragmented if we find the following characteristics in the physical, socio-economic and institutional landscape: The number of owners/users exceeds the size of land block in a given area (more than 10 owners in 10 ha), the average household land holding is less than 1 ha, more than 50% of households are composed of more than the average number of household members or co-owners, more than 50% of households have more than 2 plots with irregular shapes (not rectangular, squares) located in more than 2 different places in more than 500 m far from the homestead, with more than 2 uses (various crops in cropland, grassland, etc), heterogeneous land qualities (steep and flat slopes, mountainous and plain topography, wetlands and dry lands, fertile versus non fertile soils, sandy soils versus clay soils, etc), existence of Egalitarian principles in inheritance, land sharing and redistribution programs, domination of subsistence agriculture, absence of land consolidation practices in the area. We also consider that land is excessively fragmented if the number of parcels or plots exceeds the size of household landholding. The hidden land use and ownership fragmentation is considered when the average number of co-owners/household members is more than 2. We categorize the level of fragmentation to be low if the values are far below the average, medium if the values equal to or are around the averages and high if the values are far higher than the averages.

2.2. Positive and negative implications of land fragmentation

The effects of land fragmentation are generally viewed as negative, even though some studies find that not all the forms of land fragmentation are a problem. Bizimana et al. (2004); Sundqvist and Lisa (2006), consider land fragmentation as an obstacle to agricultural productivity and modernization. It is a major threat to efficient production system due to the fact that continuous subdivision of farms leads to small sized land holdings that may be hard to economically operate. The concepts of land fragmentation and food security have been always separated from the climate change, and linked with the agriculture production with the focus on the negative impacts of farm land fragmentation. However, land, whether fragmented or consolidated in any form, remains a fundamental asset for food security. Although popular logic is that land consolidation (especially due to increasing farm size) has direct positive effect on increasing food production, this only makes sense when food security is viewed from the lens of quantity. Nevertheless, food security is much more than quantity of food production. It has the quality, and food access perspectives which are achievable even under land fragmentation scenarios (Maxwell and Smith, 1992; FAO, 1996; Ellis, 2000; Pinsturp-Andersen, 2009; Manjunatha et al., 2013; Van der Molen, 2017). FAO (1996) from World Food Summit (WFS) in November 1996 defines **Food Security** as a status, “when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life”, and vice-versa for **Food Insecurity**. This definition stipulates the four aspects of food availability, food accessibility, as well as quantity and quality, through which food security should be measured at both national, regional, household and individual levels. Whenever one of these four aspects is not fulfilled or met, people may suffer from hidden hunger. The household food security is the application of this concept to the family level, with individuals within households as the focus of concern. Despite the provisions of the FAO definition of food security, in Rwanda, only food quantity at the national level is focused on, when measuring and showing the status of food security in the country, living behind the other aspects like food quality and food sustainability, and overlooking the household level. This leads to the formulation of non-climate resilient or inappropriate and irrelevant coping strategies. This argument is supported by the Rwanda National Food and Nutrition Plan 2013–2018 which recognizes that despite the major economic and poverty reduction progress, improvements in nutrition and household food security remains a *foundational issue* (GoR, 2014). Furthermore, the evidence based correlation between various forms of land fragmentation and the aspects of food security at household level with more focus on the climate change effects seems to be somehow overlooked by the Rwandan research community and policy makers. FAO studies (2003) show that some forms of land fragmentation (like land location and use fragmentation) can act as environmental risks management strategy by growing different crops in different growing conditions which positively impact on the nutritional balance for food quality and food sustainability at the household level. This article follows this later theory stipulating the harmonization of environmental and agriculture policies which requires the consideration of both negative and positive impacts of Farm Land Fragmentation (FLF) with the focus on food security at the household level, and the correlation of the two concepts in the study area to get the current picture of causal and effects relationships.

Land fragmentation has advantages when it comes to reducing the risk of total crop failure on the variety of soil and growing conditions. Many different types of plots allow farmers access to land of different qualities when it comes to soil, slope and micro-climatic variations. Land fragmentation can be a measure to increase food security in the context of climate change. Ciaian et al. (2015) have found that land fragmentation stimulates significantly more diversification for subsistence farm households than for market-oriented households in Albania. They have advanced that the consolidation policies that relocate

and enlarge plots would have a significant impact on reducing agricultural production diversification and that land fragmentation contributes to the food security improvement by increasing the variety of foodstuffs produced by subsistence farm households. For them, the more the differences, diversity or heterogeneity in land and soil qualities with various suitability classes and production potentials, the more the crops diversification and food stuffs diversity, the higher the nutritional balance, the higher the food quality and sustainability, the higher the food security. King and Burton (1982); McPherson (1982); Bentley (1987); Keeler and Skuras (1990), Van Dijk (2003a,b), Tan et al. (2006), Van Hung et al. (2007), Sklenicka and Salek (2008); Hristov (2009); Platonova et al. (2009); Sikor et al. (2009); Demetriou et al. (2013), have all emphasised on the importance of land fragmentation in heterogeneous communities with varying land and soil conditions, when farmers find land fragmentation as desirable for social and environmental reasons. It acts against the total harvest loss risks spreading (through disease, hail, droughts, floods and other natural disasters) and factor for diversification in various soils and growing conditions. They also find it as a tool for equal distribution of resources through the Egalitarian principles. Furthermore, this group of authors find land fragmentation to preserve biodiversity as opposed to land consolidation in some countries and cases.

Different authors including McPherson (1982); Sabates-Wheeler (2002); Sundqvist and Lisa (2006); Sklenicka et al. (2014); Hartvigsen (2013, 2014, 2015a,b), Hiironen et al. (2016); de Vries (2016); Muchová (2017); Janus et al. (2018), believe that fragmented land holdings or small scattered plots in different locations increase transport costs, supervision costs and time consuming, lead to the loss of land area through boundaries and the boundaries related conflicts and disputes, and hamper the mechanization of agriculture and the development of irrigation and drainage infrastructures within the farms thereby hindering the modernization of agriculture. Land fragmentation also limits the growth of more profitable crops on big farms on profit of the less profitable crops on small plots, and costly to alleviate. For this, these authors in their studies tend to defend the need for, and relevancy of land consolidation practices against this negative land fragmentation phenomenon, though some of them do recognise some of its social and environmental advantages above mentioned. Finally, it is noticed that banks are sometimes unwilling to take small and scattered land holdings as collateral, which prevents farmers from obtaining credit to make investments. This in turn negatively affects the quantity of agriculture production and food quantity as a component of food security. This position has been supported and found out by different authors and studies, including the recent one conducted by Sundqvist and Lisa (2006) in Vietnam, which has shown a negative relationship between land fragmentation and agriculture production.

On the other hand, different FAO land tenure studies (2003) show that land fragmentation is not a problem when *fragmented land is a risk management strategy*. Sundqvist and Lisa (2006) state that even though policy makers often point out the drawbacks of fragmentation, there is no consensus that fragmentation is strictly a negative phenomenon. Bentley (1987 cited in Sundqvist and Lisa, 2006) argues that the harm caused by fragmented land holdings is overrated and that the farmers own views often are neglected by policy makers. Fragmented land reduces the risks of the farmers by giving them the opportunity to grow a variety of crops beyond the world top four crops of wheat, rice, maize and potatoes in a variety of soils and growing conditions. For them, many different plots located in different areas allow farmers to access land of different qualities when it comes to soil, slope, micro-climatic variations etc. Fields with high yields in one year may in the following year generate much lower yields, thus several plots of the same crop also spread out the risk. In addition, a holding with several plots facilitates crop rotation and the ability to leave some land in fallow.

In reality, the Rwandan land is highly fragmented due to its high population density. About 36% of the households own 6% of the farm lands (with an average of 0.11 ha); 30% of households own 24% of farm

lands (with an average of 0.6 ha) while 24% of households own 70% of farm lands (with an average of 2 ha), besides a certain number of more than 10% of landless households. The national average holding of 0.76 ha is generally divided over 4–5 small plots, often in multiple locations. Such multiple holdings are valued by Rwandans since they can diversify their crop production across different locations and thus provide protection against natural risks and unbalanced nutrition even though it has been shown to lead to low agriculture productivity (Kahiresan and MINAGRI (2012)). According to Jayne et al. (2003 cited in GoR, 2004; Bizoza and Havugimana, 2013; Musahara et al., 2014), almost a half of the farms are small with less than 0.3 ha (45.8%) with more than 83 percent of farms being smaller than 0.9 ha as the FAO economically viable farmland size to sustain a family, since more than 50% of farming families have less than 0.70 ha. Though the studies of ECA (2004) have shown that the average sizes of farms in Africa are normally between 0.4 and 6 ha, in densely populated countries like Rwanda, this average goes below 0.5 ha. However, the forms and the extent of such fragmentation are neither yet well-known nor documented. For this, different programs embarked on to overcome this problem are broadly established regardless of the forms of land fragmentation referred to. No distinction between **Ownership fragmentation, Internal fragmentation, Location fragmentation and Use fragmentation** of the land has been shown when establishing the objectives of the LUC program for coping with land fragmentation in general, while they are different. It looks like LUC is oriented towards reducing land use fragmentation rather than land ownership, internal, location and size fragmentation. Konguka (2013) has shown how fragmented land has some benefits associated with scattered pieces of landholdings at different locations with varying soils and ecological characteristics. He argued that varieties of soils enable a farmer with a large number of small parcels to grow a wider variety of crops in comparatively small areas, thereby reducing overreliance on a limited number of crops species that can be disastrous when disease strike or pests threaten to wipe out an entire harvest. Blarel et al. (1992) argued in their study in Ghana and Rwanda that fragmentation of farmland is not as inefficient as generally perceived. They supported this view by arguing in favour of fragmentation as a tool for the management of risk, seasonal bottlenecks and food insecurity (Abubakari et al., 2016). This helps to withstand the effects of climate change in different risks prone areas like Rwanda, leading to the sustainable production of the diversity of crops the whole year, thereby increasing the nutritional balance for food quality and food sustainability as components of food security.

In summary, land fragmentation is considered good when farms are composed of many small plots located in different places with varying soils, growing conditions, topography, crops suitability and production potentials. In addition, it is relevant when it is combined with the presence of Egalitarian principles in land reforms and inheritance cultures, and climate change prone areas, high number of household members, domination of desired subsistence agriculture for crops diversification, risks management, food security, and tenure security. Therefore, if we find these elements in a case area, we consider it as a good fragmentation. Land fragmentation is considered bad if there are many owners on a small land unit, with many small parcels with irregular shapes and different uses, scattered over large distances from the homestead in a more homogenous area (homogenous topography, homogenous soils and growing conditions) with less vulnerability to climate change risks, leading to reduction in agriculture production efficiency, land related conflicts and loss/wastage of land through boundaries. Therefore, if we find these elements in a case area, we consider it as a bad fragmentation.

3. Methodology

3.1. Research approach and design

A *Mixed Methods Research Approach* was chosen for this study. Creswell (2003), Creswell et al. (2003), Creswell and Plano Clark

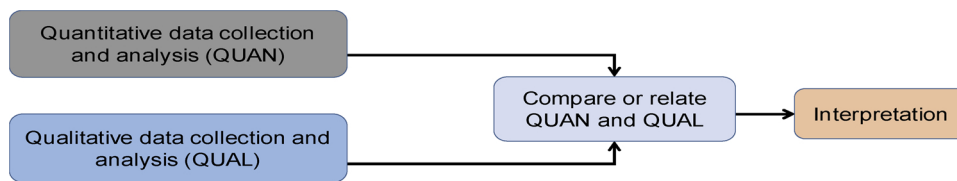


Fig. 1. Convergent parallel mixed methods research design.

Source: Authors adapted from Creswell (2014)

(2011) and Creswell (2014) note that this kind of approach gives the chance to rely on different methodologies and convergent data collection and analysis techniques which gives a better understanding of the problem and enables better solutions. Therefore, we used both household surveys about the forms and level (information about the parcel/land holding sizes, shapes, locations, uses, number of owners/users and co-owners), causes and implications of land fragmentation especially on food security as a quantitative non-experimental research design for quantitative primary data, and national data set analysis (information about parcel sizes, ownership, uses, values) for quantitative secondary data. A case study analysis of Gashora sector in Bugesera district through key informants' interviews, focus groups discussions, field observations and document review for qualitative primary and secondary data collection about the land uses, land and soil types, agro-climatic conditions, parcel shapes, causes and effects of land fragmentation was also used as part of this design. This design facilitated the authors to collect both primary and secondary data simultaneously as shown on Fig.1 below.

The choice of the above case study was driven by the fact that in the past, this sector as well as the whole Bugesera district has experienced a problem of food insecurity due to factors like land use changes, changes in weather conditions leading to prolonged droughts and changes in rainfall patterns, despite the relatively higher farm sizes in the Eastern province and the homogeneous topography of the region as compared to other parts of Rwanda. Recently, there has been increasing reduction in farm sizes, and the number of plots per land owner, and reduction in food insecurity in the district at the household level. This situation is attributed to the recent increases in population density associated with the existing customary practices of Egalitarian based inheritance, along with the desire to have plots in different growing conditions associated with the encouragement of the exploitation of swamps for agricultural purposes. These characteristics have been identified as some of the reasons (e.g. egalitarian based inheritance and desire to have plots in different growing conditions) for the increases in food security in Rwanda (Blarel et al., 1992; Huggins, 2012; Kahiresan and MINAGRI, 2012; Musahara et al., 2014). This raises questions concerning the homogeneity of ownership and use combined with the ever changing agro ecological conditions as the main drivers of food insecurity in the past (Rwanda National Food and Nutrition Plan 2013–2018; NISR, 2015). Therefore, studying the impacts of land fragmentation in a such area which has experienced the two opposite and changing scenarios at different times has been thought by the authors to give the best picture of the increasing land fragmentation and its impacts, rather than other more topographically heterogeneous regions where no significant changes in fragmentation and food security statuses and their drivers have been questioned, even though the authors plan to extend the same study to other regions of the country to get the more complete and general picture of the situation at the national level.

3.2. Research methods

Open and closed-ended questions (through questionnaire administration and semi-structured interviews) for household survey were used to collect the information about the parcel/land holding sizes, shapes, locations, uses, number of owners and co-owners for the level and forms of land fragmentation, and the causes and implications of land fragmentation especially on food security as primary quantitative data. The

unstructured key informants' interviews with open questions along with the field observations and focus groups discussions have been used for primary qualitative data collection about the land uses, land and soil types, agro-climatic conditions, parcel shapes, causes and effects of land fragmentation in 5 cells of Gashora sector, Bugesera district, Eastern province of Rwanda. The choice of all the five cells was not for the comparison purpose, but for the data variability for validity and reliability purposes. The random sampling method along with the purposive one have been used for the selection of 98 respondents representing more than 15% of the total number of households in the sector for the household survey from the simplified formula of Glenn (1992) appropriate for the small homogenous case studies, and 7 key interviews with 7 key respondents (5 cell agronomists, 1 sector agronomist, 1 sector land manager) respectively for the primary data collection. This technique of household survey in the assessment of the impacts of land fragmentation which uses the number of plots per household, their sizes, uses and shapes for physical fragmentation, and the number of owners/users in a given land unit area and co-owners per landholding for land ownership fragmentation, their causes and effects has been used by many different previous similar studies in Rwanda, Uganda, Vietnam, and Europe. Sundqvist and Lisa (2006) have used it when analysing the impacts of land fragmentation on agriculture productivity in Northern Vietnam, Hiironen et al. (2016) have used it to evaluate land fragmentation in agriculture areas in Finland, Muchová (2017) has used it to assess land ownership fragmentation by multiple criteria in Slovakia, and Janus et al. (2018) have used it when introducing a new approach to calculate land fragmentation indicators considering the adjacent plots in Poland. The *Triangulation* and *Back-checking* techniques were used to check the validity and reliability of the collected data, and chosen for their wide use in mixed studies like this one. The information about the level of land fragmentation was obtained through the calculations of different averages about the sizes and ownership through the following different ratios and sums:

Formulae

1. $Nlo = \sum_{i=1}^n loi$
2. $Nco = \sum_{i=1}^n coi$
3. $Np = \sum_{i=1}^n pi$
4. $Nploc = \sum_{i=1}^n ploci$
5. $Td = \sum_{i=1}^n di$
6. $Slb = \sum_{i=1}^n si$
7. $AvNp = Np/Nlo$
8. $AvHlts = Slb/Nlo$
9. $Avps = Slb/Np$
10. $AvNco = Nco/Nlo$
11. $Avpsco = Slb/Nco$
12. $Avpd = Td/Np$
13. $AvNploc = Nploc/Nlo$

Formulae Legend

Where,
n: The number of observations
loi: land owners/households under survey
coi: number of co-owners per households' land holding (households' members) under survey
pi: number of plots per households' land holding under survey
ploci: number of plot locations per households' land holding under survey
si: sizes of land parcels/plots under survey in ha
di: distances of plots from the homesteads under survey in km
Nlo: Number of land owners
Nco: Total number of co-owners (Household members) per land block in the study area
Np: Total number of plots in the study area or per land block
Nploc: Total number of plots locations in the study area
Td: Total plots distances from the homesteads (in Km)
Slb: Size of farm or a land block in the study area (in ha)
AvNp: Average number of plots per owner
AvHlts: Average household land holding size (in ha)
Avps: Average plot size in the study area (in ha)

AvNco: Average number of co-owners (Household members) per land holding
Avpsco: Average plot/landholding size per co-owner (in ha)
Avpd: Average plot distance from the household homestead (in km)
AvNploc: Average number of plot locations

Source: Authors (2018), compiled from the reviewed literature

The number of plots per household, the number of household members and the household's landholdings were obtained through the household survey interviews and land titles. A correlation diagram was used to show the relationships among different causes of land fragmentation in the study area. Both descriptive statistics and text description were used to analyse quantitative and qualitative data. The implications of land fragmentation from the perceptions of household members and key informants in the study area have been plotted against the aspects of food security in order to assess their relationships and answer the main research question (hypothesis). The Table B1/ Appendix B in appendices section shows the matrix summarizing the data collection and analysis methods.

4. Results

4.1. Forms and level of land fragmentation in Gashora sector

The forms and the level of land fragmentation came from combining the household survey (interviews and land titles checking) with the documentation (National data set analysis), and field observations data. Table 1, Figs. 2a, b&c present different indicators of both ownership and physical land fragmentation.

Besides the indicators in Table 1, the level of physical land fragmentation can be proved by the percentages of respondents evidencing the number of plots per household/land owner or land user (Fig. 2a),

Table 1

Forms and level of land fragmentation in Gashora sector

Source: Authors (2018), from household survey

Indicators	Values	% of Respondents /Observations	Type of Fragmentation	Level of Fragmentation	
<i>Total available land area in Gashora Sector (in ha)</i>	≈ 4500	–	Land ownership fragmentation	Visible fragmentation	Very high (Excessive)
<i>Total number of Households in Gashora sector</i>	5522	–			
<i>Size of land block under survey(Slb) (in ha)</i>	41.5	–			
<i>Number of households/land owners/users under survey (Nlo)</i>	98	–			
<i>Number of household members/co-owners under survey (Nco)</i>	610	–	Physical land fragmentation	Hidden fragmentation	Very high (Excessive)
<i>Average number of co-owners (Household members) per land holding (AvNco)</i>	6	–			
<i>Total Number of plots</i>	432	–			
<i>Average household land holding size (AvHls) (in ha)</i>	0.4	–			
<i>Average number of plots per owner/user (AvNp)</i>	4.4	–		Internal and location fragmentation	Very high (Excessive)
<i>Average plot size (Avps) (in ha)</i>	0.1	–			
<i>Average plot size per co-owner (Avpsco) (in ha)</i>	0.07	–			
<i>Number of plot locations</i>	1 location	10			
	≥ 2 locations	90			
<i>Average number of plot locations (AvNploc)</i>	3	–			
<i>Estimated distances of plots from the homestead (Espd) (in km)</i>	≤ 0.5	23			
	0.5-1	58			
	≥ 1	19			
<i>Average distance of plots from the household homesteads (Avpd) (in km)</i>	0.8	–			
<i>Production potentials of plots (Land qualities)</i>	Homogeneous	26	Value fragmentation	Value fragmentation	High
	Heterogeneous	74			
<i>Uses of plots</i>	Monoculture	62	Use fragmentation	Use fragmentation	Low
	Multiculture	38			
<i>Shapes of plots</i>	Irregular	71	Shape fragmentation	Shape fragmentation	High
	Regular	29			

their respective sizes (Fig. 2b) and uses (Fig. 2c) and shapes. The level of land use fragmentation is shown by different use types such as agriculture, residential, commercial, forestry and different farming systems (Monoculture of the priority crops versus the Multi-cropping) within agriculture use as shown in Fig. 2c and the above Table 1. It has been obtained through the household survey (interviews and land titles checking) and field observations. The level of land shape fragmentation has been obtained by checking the spatial parts of land titles for each parcel during the household survey and through different field observations in the study area. It is shown by the Regular (with a well identified geometric figure like rectangular and square) and Irregular (with no known or identified geometric figure, not rectangular nor square) forms as shown in the above Table 1. For this purpose, more than 200 land parcels were checked.

The majority of the surveyed parcels (90%) and the land titles were categorized as agriculture land as also confirmed in the field observations.

4.2. Causes/ driving forces of land fragmentation in Gashora sector

The causes of land fragmentation are shown by the perceptions of households' respondents about the ways of their land acquisition in the study area, and the ones from the key informants about the driving forces of land fragmentation along with the focus group discussions with 2 different groups of farmers and community leaders, and the review of the existing literature as shown on the Table 2 and 3 below.

The information from the focus group discussions and the review of the existing literature have revealed the increasing population growth on stable and scarce land resources combined with the traditional inheritance cultural practices (Egalitarian customary principles), the land reforms including the land sharing and redistribution programs, informal land transactions leading to the subdivision of parcels of less than 1 ha, and the variability of agro ecological conditions to cope with

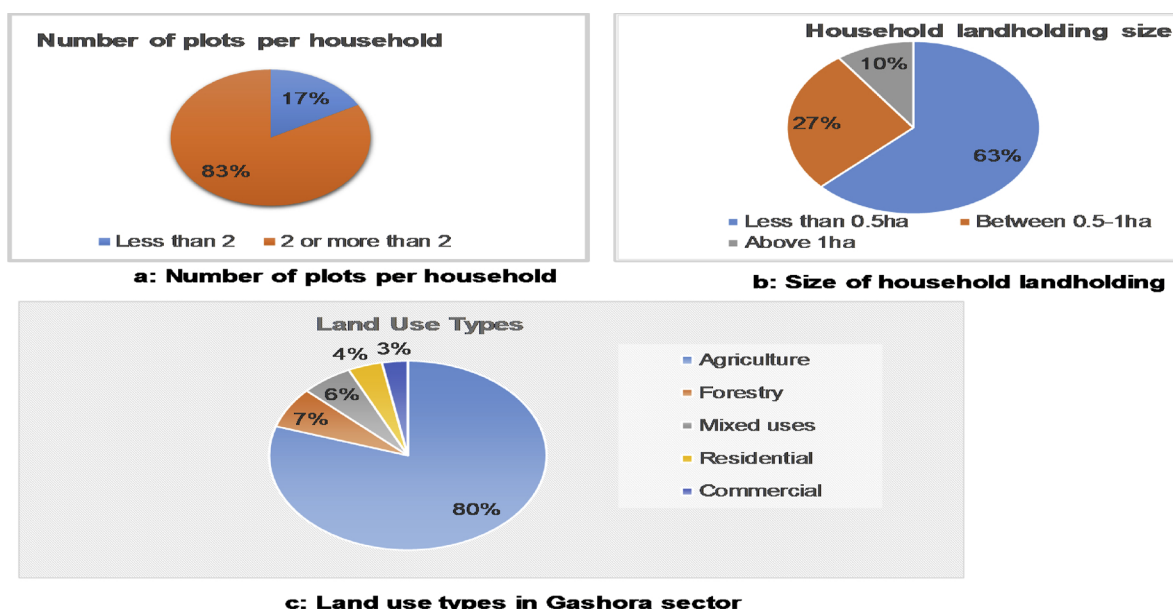


Fig. 2. Household landholding size, number of plots and their uses.

Source: Authors (2018), from household survey

the effects of climate change (long droughts), as the key driving forces of land fragmentation in Gashora sector.

4.3. Effects/Implications/Impacts of land fragmentation

The effects of land fragmentation in Gashora sector are summarized in Table 4 and Fig. 3.

5. Results interpretation and discussion

The findings demonstrate that all the five forms of land fragmentation categorized in two main forms such as physical land fragmentation and land ownership fragmentation exist in the study area, but at different levels. Table 1, Figs. 2a, b & c show that the majority of households own/use more than 2 plots of land (90% of respondents) of less than 0.5 ha (63% of respondents) and located in more than 2 locations (70% of respondents). The majority of the surveyed parcels have irregular shapes (71%) and heterogeneous production potentials of land qualities (76% of respondents), while 62% of the parcels are cultivated under the monoculture system. Furthermore, the average household landholding size, the average number of plots per household, the average plot size, the average number of co-owners per household, the average plots size per co-owner, the average number of plots locations, and the average distance of plots from the homestead in the study area are 0.4 ha; 4.4 plots; 0.1 ha; 6 members; 0.07 ha; 3 locations; and 0.8 km respectively. These values indicate the presence of a very high level (extensive) of internal fragmentation and land location fragmentation, a high level of land shape and value fragmentation, with a low level of land use fragmentation in Gashora sector as indicators of high level of physical fragmentation, since the above values are far lower than the average indicators of land fragmentation shown in Table A1/Appendix A in appendices section. The findings indicate that the number of land owners/users under survey (98 owners) and the number of co-owners (610 co-owners) exceeds the size of total land block under survey (41.5 ha). This indicates the presence of excessive land ownership and hidden fragmentation in the area, referred to the standards of McPherson (1982, 5–6 cited in Hartvigsen, 2014). The presence of this very high level of land ownership, internal, and hidden fragmentation can be explained by the persistence of Egalitarian principles within the traditional inheritance culture which leads to the subdivision of family

land among all the descendants in equal shares in both quantity and quality, as confirmed by the majority of respondents during the household survey, key informants' interviews and the literature, which show this inheritance and the traditional succession as the main way of land acquisition and cause of land fragmentation in the study area. This will be discussed later in the causes of land fragmentation. This has been exacerbated by the informal land transactions like non-registered sales, donations and successions, while the article 30 of the law governing land in Rwanda prohibits the subdivision of agricultural and livestock land parcels which would result in small parcels of less than one hectare. Such small parcels cannot be individually registered. The same law encourages the common ownership of such parcels. Though this article 30 was established to prevent the continuous land ownership fragmentation, these informal subdivisions continue to be practiced in the Rwandan rural areas due to the historical culture of individual ownership for tenure security and high registration fees (Ntuhinyurwa, 2015). The similar findings have been reported and supported by Kahiresan and MINAGRI (2012), Jayne et al. (2003 cited in GoR, 2004; Bizosa and Havugimana, 2013; Musahara et al., 2014) when they showed that the majority of Rwandans (about 36% of the households) own 6% of the farm lands with an average of 0.11 ha, and that almost a half of the farms are small with less than 0.3 ha (45.8%) with more than 83 percent of farms being smaller than 0.9 ha as the FAO economically viable farm's land size to sustain a family, since more than 50% of farm families have less than 0.70 ha, respectively. In this article, no distinction between land ownership and usership fragmentation has been drawn, since the focus was put on the number of land users/farmers in a given land block, regardless of the tenure status and

Table 2

Means of land acquisition in Gashora sector

Source: Household survey

Land acquisition in Gashora sector	Frequencies(F)	Percentages (%)
Inheritance/succession	37	38
Ascending partition	26	27
Purchase (formal& informal transactions)	23	23
Others (donations, land sharing program, diverse soil qualities, topography, agro climatic conditions etc)	12	12
Total	98	100

Table 3

Driving forces of land fragmentation in Gashora sector

Source: Key informants' interviews, focus group discussions& literature

Driving forces of land fragmentation in Gashora sector	Frequencies(F)	Percentages (%)
Inheritance, succession and marriage	7	100
Land related conflicts	5	71
Land market(formal and informal transactions)	6	86
Others (donations, land sharing program, land redistribution, variability of agro ecological conditions like soil type, slope, biodiversity conservation, etc)	7	100
Total	7	100

type (leasehold, and freehold).

The high level of land location fragmentation could be explained by the preference of the majority of Rwandan farmers in the study area (90%) to have plots in different locations with different growing conditions (soil type, slope, microclimatic variations) as a risk management strategy, in case of long droughts, floods, and diseases. Since Gashora sector and Bugesera district in general is one of the driest areas with long droughts and sunny season, uncertain or even very few precipitations (NISR, 2015), farmers prefer to have land in lowlands around the wetlands, lakes and rivers for irrigation purposes along with the ones in uplands. They also prefer to grow the mixture of early maturing and late maturing, shallow and deep crops, diseases and sun resistant crops and water-resistant crops in different locations with different suitability. This is in accordance with the findings of Kahiresan and MINAGRI (2012), Mbonigaba and Dusengimana (2013) which advanced that the multiple holdings of over 4–5 small plots often in multiple locations are valued by Rwandans since they can diversify their crop production across different locations, and thus provide protection against natural risks and unbalanced nutrition, even though it has been shown to lead to low agriculture productivity.

The findings about land use types in Fig. 2c have shown that the majority of households in the study area use their lands for agriculture purposes as confirmed by 80% of respondents and the 90% of the checked land titles along with the field observations without omitting other uses like forestry, mixed uses, residential and commercial respectively. The major part of this predominant agriculture land in the study area has been found to be cultivated through the monoculture (62% of the surveyed parcels in Table 1) under the Farm Land Use Consolidation program (LUC), where close farmers grow the same one priority crop (maize, beans, wheat, Irish potatoes, cassava and soybeans) in a synchronized way based on the so called Agro Ecological Zones(AEZ) chosen for them by the government at the national level within the Crop Intensification Program (CIP) to boost the national agriculture productivity. Only 38% of the surveyed parcels in the study area are subject to the multiple crops, where farmers grow a mixture of different priority and non-priority crops with different production capacities in the same plots often located in different areas with various production potentials. This finding confirms the low level of land use fragmentation in Gashora sector, mainly due to this LUC program, though it has been recently found in different analytical studies by different researchers like Huggins (2012), Kahiresan and MINAGRI (2012), Konguka (2013), Musahara et al. (2014), and Ntihinyurwa and Masum (2017) to be inefficient and not participatory, since farmers do not participate in the choice of the priority crops suitable to their local agro-ecological conditions (soil, microclimate, etc). They have also found it to lead to the reduction of the area cultivated by the non-priority crops, thereby increasing the susceptibility to the risks from mono-cropping, and unbalanced nutrition as the main component of food insecurity at the household level. However, different other analytical studies like the ones conducted by Kahiresan and MINAGRI (2012), Mbonigaba and Dusengimana (2013), USAID (2014), at different times found this program to be a solution to the problem of land use fragmentation and food insecurity at the national level, through its contribution to the increase in agriculture production of the priority

crops at the national level, which in turn increases the level of food quantity and food availability as components of food security as confirmed by the survey data above. With regard to the shape of parcels, the majority of the surveyed land parcels from the land titles (71%) have been found to have irregular shapes (with no well-defined geometric figure like rectangular or square) as shown in the Table 1. This could be due to the absence of any organized land subdivision or redistribution program providing the standardized shapes and sizes to be used or followed during the land subdivision process. The high level of land value fragmentation in the study area can be linked with the heterogeneous topography and soils in Gashora sector.

The findings from the focus group discussions, key informants' interviews (driving forces of land fragmentation in Table 3) and household survey (ways of land acquisition in Table 2) along with the field visits and document review about the study area, have revealed different causes of land fragmentation grouped in the following 4 categories based on the forms of fragmentation:

a) Socio-cultural causes (Egalitarian inheritance laws, Egalitarian principles in customary practices, marriage, population growth and land related conflicts): Due to the high population growth on scarce and small land resources in the study area, the existence of inheritance culture and Egalitarian principles in land distribution through succession has led to the subdivision of family land among all the heirs in equal shares of all classes and grades, resulting into very small and non-contiguous parcels located in various places with different production potentials, as confirmed by the majority of respondents(38%) in household survey and all the key informants at 100%, along with the information from focus group discussion and the relevant reviewed literature. This has led in turn to the existing status of land ownership, hidden and internal fragmentation in the area. This tendency generalized to the whole Rwanda is complemented by the high national population density of 462 inhabitants /sqkm (NISR, 2015) as the highest in Sub-Saharan Africa. In the Rwandan culture, when women get married, they have to join their husbands thereby leaving their plots in the home places often far away from their living places. This exacerbates the physical land location and internal fragmentation in the study area as mentioned by most of the respondents in key informants' interviews (100%) and focus group discussion, although no relevant literature has been found to confirm this finding. As mentioned above in the previous paragraphs, the article 30 forbidding the subdivision of parcels of less than 1 ha as a measure to cope with land fragmentation, has been accused by the majority of respondents (71% of key informants and the conclusions of focus group discussion) to lead to land ownership and use related conflicts among family members commonly owning the family land, since each family member wants to have his own portion for independent use or transaction. Despite the lack of enough supporting evidences of this finding in the Rwandan land sector literature, it has been pointed out to often lead to the hidden land use and ownership fragmentation in the study area. These findings and position are shared and quite similar to the findings of many different researchers in the literature like King and Burton (1982); McPherson (1982); Keeler and Skuras (1990); Bizimana et al. (2004); Niroula and Thapa (2005); Tan et al. (2006); Sklenicka and Salek (2008); Hristov (2009); Platonova et al.(2009); Sikor et al.(2009); Hartvigsen

Table 4
Effects of farmland fragmentation in Gashora sector (Key informants)

Forms of Land Fragmentation	Effects of Land Fragmentation	Frequencies(F)	Percentages (%)
Land Ownership Fragmentation	Loss/wastage of land through boundaries	7	100
	Increase in land ownership & boundaries related conflicts	7	100
	Decrease in yields of priority crops (Agriculture production)	5	71
Physical Land Fragmentation	Increase in Land Tenure Security (LTS) and reduction in ownership related conflicts	7	100
Land Use Fragmentation	Decrease in yields of priority crops (Agriculture production)	5	71
	Increase in land use related conflicts	6	86
	Environmental Risks Management Strategy (ERMS)	6	86
Internal Land Fragmentation	Increase of the nutritional balance through multiple crops (crops diversification)	6	86
	Obstacle to mechanization, irrigation and drainage infrastructures	7	100
	Risks management strategy (diseases and pests spreading control, droughts and floods control)	7	100
	Increase in food security through crops and food stuffs diversification (Output or agricultural production variation)	7	100
	Loss/wastage of land through boundaries and increase in boundaries related conflicts	5	71
	High transaction and production costs (given the waste of time to get to the parcels)	4	57
Land Location and Value Fragmentation	Increase of the nutritional balance through variety of crops and different growing conditions (Soil, slope, micro climate, etc)	6	86
	Environmental Risks Management Strategy (ERMS) through different growing conditions (Soil, slope, micro climate, etc), biodiversity conservation	7	100
	Decrease in agriculture production efficiency (High production costs and time), abandonment of some productive plots due to high transport costs	6	86
Land Shape Fragmentation	Environmental Risks Management Strategy (ERMS) through different growing conditions	4	57
	Decrease in agriculture production efficiency (High production costs and time)	5	71

Italic: Negative effects; **Non Italic Bond:** Positive effects.

(2013,2014,2015a,b), Sklenicka et al. (2014); Ciaian et al. (2015); Hiironen et al. (2016) and Muchová (2017), at different times in different European, Asian and African countries who all emphasise on the Egalitarian principles in inheritance practices and land reforms, marriage and familial land related conflicts to be the main basis of both ownership (hidden and visible) and internal land fragmentation. The subsistence motive reasons have been also advanced by some authors like Ciaian et al. (2015) as factors of diversification when family members with different reasons prefer to have different heterogeneous lands with different crops suitability for their crops diversification to meet their various dietary preferences.

b) Economical causes (land market, formal and informal land transactions): Different land transactions through purchase of land parcels either formally or informally have been found to lead to high internal land fragmentation and ownership fragmentation, since farmers always tend to buy additional non-contiguous land parcels of different qualities and production potentials often located in different places with different agro-ecological conditions far from the homestead, as advanced by 86% of the key informants, 23% of household survey respondents and focus group discussion conclusions. This can be explained by the fact that in the study area with heterogeneous topography (flat, hilly, and low lands, dry lands, wetlands), farmers believe that the soils are different in qualities, suitability and production potentials. For this, having different land parcels with different production potentials, increases their risks management capacity and production diversification ability.

In support to this from the literature, Ciaian et al. (2015) argued that it is somehow difficult to get additional parcels contiguous and close to the already farmed own land, thereby leading to the physical fragmentation (location and use). Additionally, the study of Grigg (1980) supports this finding by advancing that the growing land market through formal transactions like sales, purchases of land parcels contributes to land location fragmentation, since in many cases, farmers prefer or unwillingly purchase land which is not contiguous to their existing holdings or pieces of land as shares in other parcels. However, the later author argues that not all land market contributes to land fragmentation; rather, in some cases land purchase may reduce land fragmentation when farmers acquire neighbouring pieces of land to expand their holdings.

c) Physical causes (soil qualities, topography, location, shapes): From the belief of the majority of the respondents (100% of key informants, conclusions of focus group discussion) and 12% of household survey respondents, the presence of diverse soils with different soil fertility status and production potentials, diverse plots with different shapes, different locations with different microclimatic conditions, topography and biodiversity, gives the farmers the chances to diversify their output, and fight against the risks of loss of the entire production, in case of environmental risks prevalence like droughts, floods etc. For this, they prefer to have more plots with different physical properties located in different places, which leads to the physical land (use, location, internal, value and shapes) fragmentation. The small percentage of respondents who advanced the physical causes in the household survey resides in the fact that the majority of respondents were illiterate, and hence difficult to them to relate land fragmentation with more scientific and technical drivers. Furthermore, as mentioned above in the socio-cultural causes, these physical causes combined with the egalitarian principles in inheritance act as drivers of land ownership and hidden fragmentation in the study area, since all the family members receive the pieces of land of the same sizes, same qualities from all locations and all classes and grades (Keeler and Skuras, 1990; Tan et al., 2006; Ciaian et al., 2015). This position is supported by the studies of Johnson and Barlowe (1954); Buck (1964) and Netting (1972), which advanced a belief that land is not the same with respect to soil type, suitability, slope, altitude and agro-climatic location. They have found out that farmers decide to operate on many plots in different locations (land location fragmentation) to enable them reduce the risk

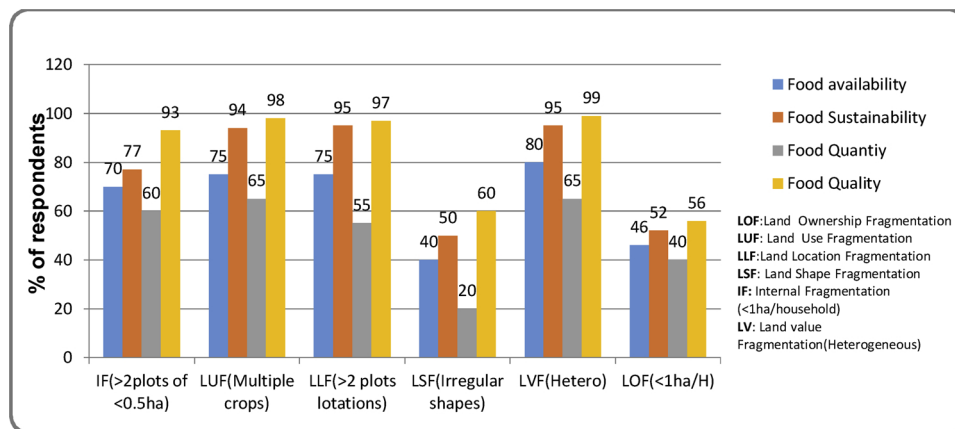


Fig. 3. Impacts of land fragmentation on food security aspects (Household survey).

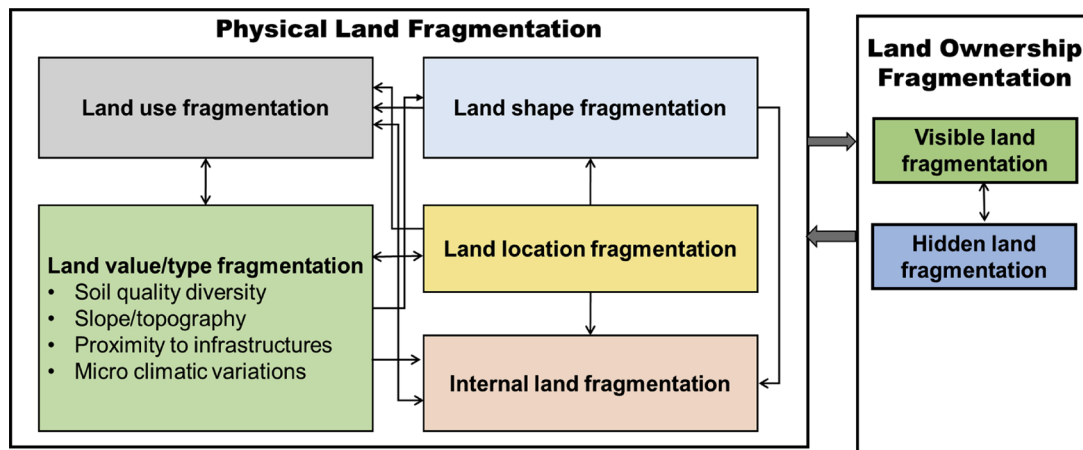


Fig. 4. Causal interactions among land fragmentation forms.
 Source: Authors (2018)

of total loss of output due to perils such as floods, fires and droughts, since the scattering of plots also enables them to diversify their cropping mixtures across different growing conditions.

d)Operational/Normative/Institutional causes (land sharing program in Rwanda (1995–2012), land use consolidation program, Article 30 of the law governing lands in Rwanda, land redistribution programs before and after the 1994 Genocide and some rural infrastructures development):The findings from all data sources have revealed different land policies in the study area like the article 30 of land law forbidding the subdivision of land parcel less than 1 ha and encouraging the co-ownership of family land, LUC program, land sharing and redistribution programs after the 1994 genocide against Tutsis, to lead to hidden land use and ownership fragmentation as evidenced by 12% of respondents in household survey, 100% of key informants, and the key conclusions of focus group discussion, supported by some governmental reports and analytical literature about those policies and programmes. As an explanation to this, Rwandans like independency in ownership and use of their assets. In this regard, though the article restricts such subdivision, the customary practices and other social economic reasons like land use and ownership related conflicts push the persistence of these informal subdivisions all over the rural parts of the country without registering those resulting small plots. The Land Use Consolidation (LUC) program has also been stressed on to supplement this article 30 in stimulating these conflicts, when all the co-owners of the land parcels are obliged to grow one single priority crop which in some cases do not match the individual preferences [Ntuhinyurwa and Masum \(2017\)](#). In this regard, the land conflicts can be confirmed as a cause of land subdivision for independent individual ownership and

use, hence a cause of land ownership and use fragmentation. The study of [Ciaian et al. \(2015\)](#) supports this position by arguing that different family members may prefer to grow different crops to meet their various dietary preferences. The land sharing program which used the Egalitarian principles for the redistribution of land among the 1959 returning refugees and the formal occupants of those lands at the time in equal shares also exacerbated the land ownership and physical land fragmentation problem in the study area as advanced by the majority of respondents. Different infrastructures development like roads construction disperses the contiguous land parcels in small pieces, leading in turn to physical internal fragmentation as supported by the reviewed global literature and some respondents during the key informants' interviews and focus group discussions.

In summary, the findings have revealed the causal interactions among the forms of land fragmentation as shown on the cross-cutting diagram in [Fig. 4](#) below.

The above diagram demonstrates that some forms of land fragmentation induce other forms and vice versa. The double arrow shows the mutual or bilateral interactions, while the single arrow shows the unilateral influence of one form to another. The diagram is a result of the combination of author's knowledge, primary data and the review of the existing literature about land fragmentation and its causes.

For the impacts of land fragmentation, the results in the [Table 4](#) from the key informants' interviews and focus groups discussion reveal the increase in land tenure security, and reduction in ownership and use related conflicts as the key positive effects of land ownership and use fragmentation as advanced by 100% of respondents. With regard to the reduction in land ownership and use related conflicts, it has been

argued that when each family member owns his parcel, there is an independency in use and management of that parcel. This in turn reduces the occurrence of intra familial land conflicts on the co-owned parcels, thereby increasing the tenure security, when the small individually owned parcels are legally registered. Furthermore, the majority of the key informants have reiterated the Environmental Risks Management Strategy (ERMS) through different growing conditions (Soil, slope, micro climate, etc.) and multiple crops, and the increase in nutritional balance through the variety of crops and different growing conditions as an indicator of food quality to be the main effects of land location, use and shape fragmentation at 100% and 86% respectively. To support this version, the results from the household survey about the impacts of land fragmentation on food security at the household level have shown the increase in food quality and food sustainability as the key positive impacts of all the forms of land fragmentation with land value (99&95% of respondents), use (98&94% of respondents), location (97&95% of respondents) and internal (93&77% of respondents) fragmentation respectively at higher levels as shown in the above Fig. 3. These findings show that not all the land fragmentation forms are a problem, since there are some cases where *fragmented land is a risk management strategy especially in areas with high microclimatic variations* like Rwanda, as supported by different *FAO land tenure studies (2003)*. The same findings are shared and supported by *Konguka (2013)* who indicates how fragmented land has some benefits associated with scattered pieces of landholdings at different locations with varying soils and ecological characteristics. He argues that varieties of soils enable a farmer with a number of small parcels to grow a wider variety of crops in comparatively small areas thereby reducing overreliance on a limited number of crops species that can be disastrous when disease strike or pests threaten to wipe out an entire harvest. Based on the explanations from the focus group discussion, this helps to withstand the effects of climate change in different risks prone areas in Rwanda especially in the study area, leading to the sustainable production of the diversity of crops throughout the whole year, thereby increasing the nutritional balance for food quality and food sustainability as components of food security. The findings of *Sundqvist and Lisa (2006)* about the impacts of land fragmentation on agriculture productivity in Northern Vietnam also confirm the same version of advantages of land use and location fragmentation. This positive position of land fragmentation is also similarly supported by the findings of *Ciaian et al. (2015)*, since they have found that land fragmentation stimulates significantly more diversification for subsistence farm households than for market-oriented households in Albania. They have advanced that the consolidation policies that relocate and enlarge plots would have a significant impact on reducing agricultural production diversification and that land fragmentation contributes to the food security improvement by increasing the variety of foodstuffs produced by subsistence farm households. For them and similar to our findings, the more the differences, diversity or heterogeneity in land and soil qualities with various suitability classes and production potentials, the more the variety in growing conditions, the more the crops diversification and food stuffs diversity, the higher the nutritional balance, the higher the food quality and sustainability, the higher the food security. This converge with the Sustainable Development Goals (SDGs 2, 13 and 15) of achieving Zero Hunger, adaptation to climate change, and the protection and sustainable use of land resources through the prevention and/or reduction of biodiversity loss in the Agenda 2030 respectively. The achievement of these goals stipulates the focus on the sustainable and climate smart agriculture which requires the growth of multiple crops with different adaptation capabilities on plots spread in different areas with different suitability and growing conditions, in order to promote the biodiversity of cultivated plants and livestock, increase the diversity of food stuffs to support the nutritional balance and sustainable food production throughout the whole year, rather than the widely known market-oriented agriculture on big farms often promoting the monoculture and exposing the loss of the entire production in case of environmental risks

outbreak as result of climate change. This climate resilient agriculture requires a sound recognition of the positive impacts of land use, location, value and in some cases of internal fragmentation discussed above. In support to our findings, *King and Burton (1982)*; *McPherson (1982)*; *Bentley (1987)*; *Keeler and Skuras (1990)*, *Van Dijk (2003a,b)*, *Tan et al. (2006)*, *Van Hung et al. (2007)*, *Sklenicka and Salek (2008)*; *Hristov (2009)*; *Platonova et al. (2009)*; *Sikor et al. (2009)*; *Demetriou et al. (2013)*, have all emphasized on the importance of land fragmentation in heterogeneous communities with varying land and soil conditions, when farmers find land fragmentation as desirable for social and environmental reasons. It acts as total harvest loss risks spreading management strategy (through disease, hail, droughts, floods and other natural disasters) and factor for diversification in various soils and growing conditions. This strengthens the idea of specifying land consolidation projects to different local conditions, rather than blindly following the ever growing panacea of transplanting modern land consolidation systems from more homogenous and market-oriented European agriculture contexts in different, heterogeneous local contexts which in many cases end up in failures. Similar to their findings, the group discussions and key informants' results have also mentioned the physical land fragmentation as a tool for equal distribution of resources through the Egalitarian principles, and driver of biodiversity conservation as sometimes opposed to the land consolidation practices in many countries with more market oriented and monoculture based agriculture.

On the other hand, besides the findings about the positive impacts of land fragmentation, *Table 4* also indicates the main negative impacts of different forms of land fragmentation to be the decrease in agriculture production efficiency (high production costs due to time and transport) by 86%, 71%&57% of key respondents for land location and value, land shape, and internal fragmentation respectively; Decrease in yields of priority crops (agriculture production) by 71% of key respondents for both land ownership and use fragmentation respectively; Obstacle to mechanization, irrigation and drainage infrastructures by 100% of key respondents for internal land fragmentation; Increase in land ownership, boundaries & use related conflicts by 100% & 86% of key respondents for land ownership and use fragmentation respectively; Loss/wastage of land through boundaries by 100% & 71% of key respondents for land ownership and internal fragmentation respectively. It has been argued during the key informant's interviews and focus group discussions that the fact of holding many different small parcels in different locations with irregular shapes and scattered uses makes the farming activities more difficult to supervise, increases the inputs and outputs transport costs and time consuming, thereby reducing the agriculture production efficiency. Furthermore, the small plots also reduce the national agriculture production of the priority crops per ha, since the evidences have shown the agriculture intensification of small plots in subsistence agriculture to be difficult. This multiple holding by many different owners has also been argued by the key informants to increase the number of boundaries leading to the occurrence of boundaries related conflicts and the loss of some land area through boundaries. It is considered as a major threat to efficient production system due to the fact that continuous subdivision of farms leads to small sized land holdings that may be hard to economically operate. In addition to that, the results from the household survey have also revealed the negative linkages between different forms of land fragmentation (ownership, shape location) and some aspects of food security (food quantity, food availability and food sustainability). Only 20%, 40% & 55% of the respondents have positively linked the high level of land shape, ownership and location fragmentation with the high level of food security in the study area respectively, while 40%&46% linked them with food availability. Generally, the data in *Fig. 3* show land ownership and shape fragmentation to have the lowest levels of positive impacts on food security in the study area, as also confirmed by the percentages of respondents who linked them with food sustainability (50%&52% respectively), and food quality (60%&56% respectively),

besides the above mentioned reverse linkages with food quantity and availability. This automatically highlights them as the main problematic land fragmentation situations in the study area, and targets for coping strategies like subdivision restrictions, and modern land consolidation instruments. In the support of this negative side of land fragmentation in Rwanda, the review of the existing literature has shown that GoR (2004), Musahara and Huggins (2005), Kahiresan and MINAGRI (2012), Ntirenganya (2012 cited in USAID, 2014), Mbonigaba and Dusengemungu (2013) find land fragmentation as a negative factor of food security through the reduction of the efficiency of agriculture production at the national level, since the yield per HA is small when agriculture is done on small plots far away from the residence due to the high production costs, and call for the emphasis on land consolidation practices to counter this internal and location fragmentation, regardless of their positive impacts. This slight difference from our finding resides in the fact that most of the previous studies did not consider all the forms of land fragmentation, the micro climatic variations, the climate change challenge and all the aspects of food security. Their studies were only focusing on land ownership and location fragmentation as a threat to the quantity of agriculture production and food quantity, thereby ignoring the nutritional balance and quality aspects. In this regard, the authors argue that the choice of strategies to cope with land fragmentation should be merely based on an in depth assessment of the available problematic forms, local agro-ecological conditions, social, economic and political contexts, along with the ever growing climate change global threat, since not all the land fragmentation forms are problematic. According to Demetriou (2014), there exist different policies/strategies to tackle or control land fragmentation. These range from legislative strategies (restrictions regarding inheritance, minimum size of parcel division, absentee land-owners, prevention of transfer to non-farmers, leasing, imposing a maximum limit on the size of a holding, etc) for land ownership and internal fragmentation control, land management strategies/approaches including the famous land consolidation, land funds and land banking, voluntary parcel exchange and cooperative farming for physical (internal, location, use and shape) and ownership land fragmentation control for market oriented/commercial agriculture purposes, and specific land protection policies/programmes to prevent agricultural land from being developed for housing or commercial use as a tool for land use fragmentation control. For this, it would be worth wealthy to wisely choose among the above strategies which ones would be specific to the problematic land fragmentation local situation, based on evidences based participatory feasibility and suitability studies, rather than always thinking of land consolidation as a panacea to all land fragmentation situations. The modern land consolidation instrument as it is applied in the European context to control the internal, location and shape fragmentation problems to increase agriculture production efficiency through the increase in well-organised farm sizes in the context of commercial and mechanised agriculture can not necessarily solve all land fragmentation problems in the African rural context dominated by the subsistence agriculture as confirmed/proved by the above findings in the rural Rwandan case study. Therefore, it should be mainly applied with probable successful results in more homogenous areas with less variability in agro-ecological, physical (soil, slope, water, etc), socio-economic and climatic conditions in the developing countries with quite similar context to the European one. Otherwise, there is a need for the development of a more local context specific land consolidation approaches different from the modern one, in more heterogeneous areas.

Since this study has been conducted on a small quite homogeneous area, using only simple methods for measuring land fragmentation, the findings have been only limited to Gashora sector in Bugesera district due to high microclimatic variations in Rwanda, heterogeneity of the country's social, economic and physical aspects. They cannot be generalized to the whole country, though previous studies in different regions have shown some similarities. However, the empirical findings

are in line with the pre-established hypothesis, since they indicate that higher levels of physical land fragmentation (location, use, shape, value and internal), and hidden land ownership fragmentation act as risks management strategy, through crops and food stuffs diversification in the study area. Furthermore, the findings have also evidenced the positive correlation of some land fragmentation forms (use, location, value and internal) with the nutritional balance for food quality and food sustainability as components of food security at the household level in the study area, despite the negative relationship between land ownership and shape fragmentation, and food quantity and food availability. For this, the classical assumption of considering land fragmentation as always a bad phenomenon is not true, since the evidences in the study area have shown its positive side, when it comes to the heterogeneity of social, cultural, economic and physical conditions in areas like Gashora sector. Hence there is no uniform replication of the classical theory of land fragmentation, since it varies upon the type of fragmentation and the circumstances along with the social, economic, cultural, political, physical and environmental conditions of an area.

6. Conclusions

The discourse on land fragmentation has so far been rather idiosyncratic (i.e. focusing on single aspects only) and rather negative (being an obstacle to agriculture production and food security). The consistency of this narrative has contributed at times to inappropriate strategies which were not climate resilient. The resultant land consolidation practices may have increased agricultural production at the national level and significant derived benefits in the European context, but they have also exacerbated the problem of nutritional balance, food quality and food sustainability as components of food security at the national and household levels. In contrast, the findings of this study have indicated the positive impacts of some forms of land fragmentation (ownership, use, internal, value and location) in the study area at different levels. They have proved that a high level of fragmentation exists in the study area, both in terms of land ownership (visible and hidden) and physical landscape (internal, location, value and shape), and a low level of land use fragmentation as a result of the ongoing Land Use Consolidation program (LUC) which is a national controversial strategy to broadly cope with land fragmentation problems in Rwanda. The dominant reasons of these high levels are that land users perceive land fragmentation as an effective risks management strategy which would positively affect food quality, food sustainability and food security as proved by the data from the household survey, key informants' interviews and focus groups discussion. Multiple land holdings with different shapes in different locations allow farmers to grow multiple crops with different adaptation capacities in different growing conditions (soil type, slope, microclimate variations, etc.). Furthermore, the findings from all the data sources in this article have shown that some forms of land fragmentation (use and ownership fragmentation) can contribute to the reduction of land ownership and use related conflicts through the increase of individual ownership and use independency, despite its negative impacts on agriculture production efficiency, loss of land through boundaries and boundaries related conflicts. The same findings also show the physical land fragmentation as a tool for biodiversity conservation. Therefore, the study confirms the positive impacts of land use, location, internal, value, ownership and shape fragmentation on food sustainability and food quality as components of food security at the household level as a new finding in this field, based on the evidences from the household survey (correlation of present high levels of land fragmentation forms in the study area, with the aspects of food security at the household level), key informants interviews and focus group discussions as pre-assumed in the study hypothesis. In this regard, the respondents have advanced that the multiple holding of small plots with different shapes in multiple different locations allow the farmers to grow different crops with

different adaptation capacities (shallow versus deep rooted crops, droughts resistant versus floods resistant crops, early maturing versus late maturing crops, perennial versus cash crops, cereals versus vegetables and tubers, disease resistant and non-resistant crops) in different areas with different suitability and growing conditions (soil type, slope, microclimate variations etc.), as a risks management and climate change adaptation strategy through the prevention of the total loss of agriculture production in case of environmental disasters outbreak. This increases the level of the nutritional balance, food sustainability and food quality as components of food security at the household level as a result of crops and food stuffs diversification, as confirmed and supported by the literature on the positive side of land fragmentation.

Most of the chosen theories like the classical theory of land fragmentation as a negative phenomenon, FAO theory of land fragmentation as an environmental risk management strategy and food security driver, the food security theory as a multidimensional concept, and the methodology used in this research have been useful. The information about the indicators of land fragmentation, their causes, and implications (positive and negative) on food security could not have been obtained without using the household survey, field visits and literature review, key informant's interviews and focus groups discussions respectively, along with the descriptive statistics, correlations and texts analysis methods. The correlation of the level and forms of land fragmentation and different aspects of food security has helped to draw the useful insights about the topic and confirm our hypothesis (land fragmentation as positive phenomenon), though there were some methodological limitations like small study area, no use of more sophisticated measurements of land fragmentation like different indexes as

mentioned in the previous section.

Therefore, the study recommends an adaption to land fragmentation discourse. This adaption concerns the consideration of some forms of land fragmentation like physical land fragmentation (use, value, internal, location, shape) as a climate resilient solution to food insecurity, when preparing the coping and control strategies/policies to land fragmentation and food insecurity in climate change vulnerable and prone areas like Rwanda, in order to support the achievement of the Sustainable Development Goals (SDGs 2, 13 and 15) of meeting Zero Hunger, adaptation to climate change, and the protection and sustainable use of land resources through the prevention and/or reduction of biodiversity loss in the Agenda 2030 respectively. Since the research has been limited in scope and methodology, the authors recommend further detailed and generalized research on the level of land fragmentation covering a big heterogeneous area of Rwanda, using all the globally recognized methods for measuring land fragmentation, and the assessment of the suitability and necessity of land consolidation practices in the country. The choice of any strategy to control land fragmentation should be based on a feasibility study prior to its implementation in the local context for the benefits of local farmers. The modern land consolidation system would be mainly applied with probably successful results in more homogenous areas with less variability in agro-ecological, physical (soil, slope, water, etc), socio-economic and climatic conditions, and this should be the main focus in the Rwandan context as a climate change resilient and adaptation strategy to land fragmentation and food insecurity problems as stipulated by the SDGs.

Appendix 1 Types and attributes of conceptualising land fragmentation

Table A1

Types and attributes of conceptualising land fragmentation.

Source: Authors (2018), from the literature review.

Emphasis on	Addressed in (article, literature)	Criteria to consider which result in fragmentation. There is fragmentation in parcels or in an area if:	Implications of each type of fragmentation
Absolute physical features or physical fragmentation (shapes or sizes of individual parcels, size of household land holding or farm, Number of parcels per household holding or farm, length of boundaries, distances from / to individual parcels)	King and Burton (1982); McPherson (1982); Keeler and Skuras (1990); Sabates-Wheeler (2002); Van Dijk (2003a,b); Sundqvist and Lisa (2006); Tan et al. (2006); Van Hung et al. (2007); Hristov (2009); Platonova et al. (2009); Sikor et al. (2009); Ciaian et al. (2015); de Vries (2016); Demetriou et al. (2013); Hiironen et al. (2016); Janus et al. (2018)	<ul style="list-style-type: none"> There are Irregular shapes of parcels (not rectangular nor square) The size of the parcel or a farm is smaller than 1 ha. The number of parcels or plots per household land holding/farm is equal to 2 or more. Non-contiguous plots located in 2 or more different places Boundaries between parcels are long (indicating a meandering shape) Distance from house to parcel is longer than 500 m 	<ul style="list-style-type: none"> Difficult to harvest and reach parcels High production costs through transport of inputs like fertilizers and seeds. Low agriculture production efficiency (Small yields with high costs per small unit area Loss/wastage of land through boundaries Increase in boundaries related conflicts Risks management strategy through diversification of crops on plots with various production potentials Facilitates the Crop rotation flexibility/diversity and increases biodiversity Obstacle to market oriented agriculture High transaction costs (given the waste of time to get to the parcels) High dependencies (on existing roads, and infrastructures) Obstacle to mechanization, irrigation and drainage infrastructures Risks management strategy (diseases and pests spreading control, droughts and floods control) Output or agricultural production variation Increase in food security through crops and food stuffs diversification Loss/wastage of land through boundaries and increase in boundaries related conflicts
Relative or aggregate physical features (i.e. average size, average shapes, average distances, average number of plots/parcels)	King and Burton (1982); McPherson (1982); Keeler and Skuras (1990); Blarel et al. (1992); Van Dijk (2003a,b); Sundqvist and Lisa (2006); Tan et al. (2006); Platonova et al. (2009); Hristov (2009); Demetriou et al. (2013); Ciaian et al. (2015); Hiironen et al. (2016); Muchová (2017)	<ul style="list-style-type: none"> In an area under consideration the majority (e.g. more than 50%) have irregular shapes In an area more than 50% of the parcels are smaller than 1 ha. More than 50% of household land holdings/farms are divided in 2 or more parcels. More than 50% of the household landholding /farms have plots or parcels located in 2 or more places at the distances of more than 500 m from the homestead. 	<ul style="list-style-type: none"> High transaction costs (given the waste of time to get to the parcels) High dependencies (on existing roads, and infrastructures) Obstacle to mechanization, irrigation and drainage infrastructures Risks management strategy (diseases and pests spreading control, droughts and floods control) Output or agricultural production variation Increase in food security through crops and food stuffs diversification Loss/wastage of land through boundaries and increase in boundaries related conflicts

(continued on next page)

Table A1 (continued)

Emphasis on	Addressed in (article, literature)	Criteria to consider which result in fragmentation. There is fragmentation in parcels or in an area if:	Implications of each type of fragmentation
Socio-legal features (i.e. land ownership, land use) for ownership and use fragmentation	King and Burton (1982); Keeler and Skuras (1990); Sabates-Wheeler (2002); Van Dijk (2003a,b); Tan et al. (2006); Sklenicka and Salek (2008); Hristov(2009); Sikor et al. (2009); Demetriou et al. (2013); Sklenicka et al.(2014); Hartvigsen (2013, 2014, 2015a,b); Hiironen et al. (2016); Muchová(2017)	<ul style="list-style-type: none"> Many land owners exist in a relatively small area Many land users exist in a relatively small area Many overlapping claims exist Many different crops exist in a single farm/household holding or within a small area More than 2 land use types exist in a household landholding (arable land, grassland, residential, forest land etc) Large number of household members (more than 4) co-owning a small land parcel(less than 1 ha) 	<ul style="list-style-type: none"> Abandonment of some potential agriculture lands distant from the homestead (difficult to access) Obstacle to mechanization, irrigation and drainage infrastructures Increase in land ownership related conflicts Increase in familial land use related conflicts in case of co-ownership Difficult land use planning Equal distribution of land (Equal and Equitable treatment) Inheritance flexibility Increase in tenure security through the use and ownership independency Household food self-sufficiency Abandonment of some potential agriculture lands distant from the homestead (difficult to access)
Bio-physical features (soil type, soil quality, biodiversity, environmental quality, ecological features, etc.) for value, use, ownership and location fragmentation	King and Burton (1982); McPherson (1982); Keeler and Sukras (1990); Blarel et al. (1992); Van Dijk (2003a,b); Sundqvist and Lisa (2006); Tan et al. (2006); Sklenicka and Salek (2008); Hristov(2009); Platonova et al., (2009); Sikor et al.(2009); Demetriou et al.(2013); Ciaian et al.(2015)	<ul style="list-style-type: none"> Land parcels with diverse slopes (Steep slopes vs flat slopes) ; fertile and non- fertile soils ;wetlands versus mountainous ; rainfed versus dry lands ;agriculture suitable versus unsuitable lands ; heterogeneous soils, topography, flora and fauna, etc. 	<ul style="list-style-type: none"> Increase in food security through crops and food stuffs diversification Risks management strategy through diversification of crops on plots with various production potentials (diseases and pests spreading control, droughts and floods resistance) Output or agricultural production variation Strengthens subsistence agriculture Increases land use and ownership fragmentation Increase in land use and ownership related conflicts Increased biodiversity Equal distribution of land (Equal and Equitable treatment) Inheritance flexibility Increases land use and ownership fragmentation Loss/wastage of land through boundaries and increase in boundaries and ownership related conflicts Reduction in agriculture production efficiency/obstacle to market oriented agriculture Increase in agriculture production diversification and food stuffs diversity
Normative features (derived from policy, e.g. spatial justice, Land reforms, land market)	King and Burton (1982); Keeler and Sukras (1990); Tan et al. (2006); Sklenicka and Salek(2008); Hristov(2009); Platonova et al.(2009); Sikor et al.(2009); Sklenicka et al. (2014); Ciaian et al.(2015); Hartvigsen (2013, 2014, 2015a,b)	<ul style="list-style-type: none"> Existence of the egalitarian inheritance principles in the area Existence of land sharing and distribution programs in the area Absence of land consolidation, sizes restrictions and land speculation control programs in the area Domination of subsistence agriculture in the area 	

Appendix 2 Overall Research Matrix

Table B1
Overall research matrix.
Source: Authors (2018).

Research variables	Indicators/Required information	Sources of data	Data collection methods	Data analysis methods
Forms and level of land fragmentation in Gashora sector/ Rwanda	Physical Fragmentation (Number of plots per household, Total number of plots in the study area or per land block, Size of farm or a land block in the study area (in ha), Average number of plots per owner, Average household land holding size (in ha), Average plot size in the study area, Average size of plot per co-owner (in ha), Land use types, land shapes, land types)	Land owners (Farmers), land titles, Literature and field visits.	Household survey through semi-structured interviews, and field observations (primary data), Literature/document review (secondary data).	Descriptive statistics (percentages, means or averages and frequencies), images analysis
	Ownership Fragmentation (Number of land owners, Total number of co-owners (Household members) per land block in the study area, Average number of co-owners (Household members) per land holding, Size of farm or a land block in the study area (in ha), Average number of plots per owner, Average household land holding size (in ha))	Land owners (Farmers), land titles, Literature and field visits.	Household survey through semi-structured interviews, and field observations (primary data), Literature/document review (secondary data).	Descriptive statistics (percentages, means or averages and frequencies), images analysis
	Social-cultural and economic causes (Land market, inheritance, land transactions, marriage, Egalitarian principles, customary practices etc)	Government officials (Land managers, agronomists, Agriculture Land Policy makers), Land owners (Farmers) local leaders, Literature.	Household survey through semi-structured interviews, Key informants unstructured observations (primary data), Literature/document review (secondary data)	Descriptive statistics (percentages, means or averages and frequencies),Texts (Reduction, Display, and conclusions drawing)
Causes/driving forces of land fragmentation in Gashora sector/ Rwanda	Biophysical causes (Land and soil qualities, climatic conditions, topography, etc)	Government officials (Land managers, agronomists, Agriculture Land Policy makers), Land owners (Farmers), Literature and field visits	Household survey through semi-structured interviews, Key informants unstructured observations (primary data), Literature/document review (secondary data)	Descriptive statistics (percentages, means or averages and frequencies),Texts (Reduction, Display, and conclusions drawing)
	Normative causes (land reforms, land policies, etc)	Government officials (Land managers, agronomists, Agriculture Land Policy makers), Land owners (Farmers) local leaders, Literature	Household survey through semi-structured interviews, Key informants unstructured observations (primary data), Literature/document review (secondary data)	Descriptive statistics (percentages, means or averages and frequencies),Texts (Reduction, Display, and conclusions drawing)
	Positive implications and food security	Government officials (Land managers, agronomists, Agriculture Land Policy makers), Land owners (Farmers), Literature and field visits, local leaders	Household survey through semi-structured interviews, Key informants unstructured observations (primary data), Literature/document review (secondary data)	Descriptive statistics (percentages, means or averages and frequencies),Texts (Reduction, Display, and conclusions drawing), correlations
Effects/implications of land fragmentation in Gashora sector/Rwanda	Negative implications	Government officials (Land managers, agronomists, Agriculture Land Policy makers), Land owners (Farmers), Literature and field visits, local leaders	Household survey through semi-structured interviews, Key informants unstructured observations (primary data), Literature/document review (secondary data)	Descriptive statistics (percentages, means or averages and frequencies),Texts (Reduction, Display, and conclusions drawing),correlations

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